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PROBLEM ANALYSIS

THE SOUTHERN PINE BEETLE

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Introduction

In 1959, Thatcher[1/] prepared a project analysis in which he reviewed the literature and outlined general research needs for 5 species of southern pine bark beetles. A supplement by Moser and Pickard[2/] in 1964 added a list of known insects and mites associated with the beetles and indicated the possible biological roles of these associates.

The analysis reported here is restricted to the southern pine beetle Dendroctonus frontalis Zimmerman and supersedes the earlier analysis (see addendum). The paper updates research findings since 1959, outlines existing research efforts, defines present project objectives, and spells out project priority needs in the light of new developments and current thinking.

For background information on the biology and ecology of the southern pine beetle and on the interrelationships of bark beetle species, the researcher is referred to Thatcher's review.

Despite over a half century of research which has accumulated a considerable fund of knowledge about the insect, man still lacks information that will permit him to cope effectively with recurring depredations. Research to date has turned up very few points in the beetle's behavior and requirements that can be used to advantage in reducing timber losses. The assignment of the Alexandria Forest Insect Research Project is to explore

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1/ Thatcher, R. C. 1959. A project analysis: the southern pine bark beetles. Southern Forest Expt. Station (ET 8.0) SO-2203-1.0.

2/ Moser, J. C. and Pickard, L. S. 1964. First supplement: problem analysis: the southern pine bark beetles. SO-2203-1.0

the nature of the insect in relation to its environment and to determine the fundamental causes of epidemics for the purpose of revealing opportunities to prevent or minimize infestations.

To meet this objective, Project research will be concerned with a wide range of studies, covering the interaction of the southern pine beetle with other bark beetle species and the factors affecting attack, and brood establishment and development. It will investigate environmental associations and silvicultural aspects, and the various means that can be utilized to make pine forests inhospitable to the insect. It will study the predators, parasites, disease-causing organisms, and other agents that affect beetle populations. Thus, Project research will involve tree physiology, weather, soils, stand conditions, stand disturbances, and other influences that may directly or indirectly affect the beetle and its associated organisms.

The Problem

The southern pine beetle is distributed from New Jersey throughout the southeastern United States, New Mexico, Arizona, Mexico, and southward to the Republic of Honduras, C. A. (46). Within its range, the insect has a greater potential for destroying the raw materials of the pine pulp and paper, plywood, and lumber industries than any other destructive agent.

Severe epidemics occur somewhere almost every year. Annual losses in the southeastern United States are estimated to exceed 100 million board feet of sawtimber and 20 million cubic feet of growing stock. Roughly one million dollars is spent annually in suppressing the insect by chemical means. For one reason or another, only about one half of the beetle-killed timber is salvaged. Further, blue-stain fungi carried by the

insect cause a degrade loss of about 10 dollars per M.B.F. Recently in Honduras, the southern pine beetle destroyed 8-1/2 billion board feet of high-quality timber in a 2-year period (3). Because of a poor transportation system, the lack of power saws, spray equipment, and chemicals, and the inability of the Republic to organize a control program quickly enough, most of the infested timber was lost to secondary insects and decay.

Research by the Southeastern and Southern Forest Experiment Stations has developed means of suppressing the insect by felling infested trees and thoroughly spraying the bark surface with benzene hexachloride formulations. By so doing, parent beetles and their broods either are killed in place or die as or after they chew exit holes through the treated surface. Spread of spot infestations thus may be prevented and millions of dollars worth of timber saved: yet, epidemics continue to recur at irregular intervals of several years --often in the same stands.

The problem, therefore, is to develop silvicultural and biological measures that will prevent rather than control future outbreaks. This approach, while time consuming and complex, will provide more economical, long-lasting, and safer controls than are possible by direct means.

Literature Review

The literature on the southern pine beetle prior to 1960 has been thoroughly reviewed by Dixon and Osgood (15), Osgood (29), and Thatcher (36, 37). In 1963, Wood (46), in combining D. mexicanus Hopkins and D. arizonicus Hopkins with D. frontalis, provided a broader and more up-to-date literature review pertaining to the new composite.

Because of the great similarity of the morphology, biology, and habits of the southern pine beetle to those of the western pine beetle, D. brevicomis Lec., the attention of the researcher is directed to the

comprehensive work of Miller and Keen (28) which summarizes 50 years of research on the latter insect. Many facets of this research, particularly from the standpoint of beetle and host-tree relationships, host-tree resistance and susceptibility, indirect control by forest management, and natural enemies, have application to the southern pine beetle problem.

In recent years, important basic research has been performed on southern pine beetle attractants, mass rearing in bolt material, artificial diet, seasonal behavior, and pattern of attack. Vité and Gara (43), for example, found that the southern pine beetle and the 3 species of southern Ips bark beetles (I. avulsus Eichh., I. grandicollis Eichh., and I. calligraphus Germ.) were attracted in large numbers by volatile materials emanating from log sections recently attacked by the respective species. In the absence of material freshly infested by their own kind, the 3 Ips species responded to logs occupied by the southern pine beetle. In addition, the southern pine beetle responded to an attractant collected from ponderosa pine that had been infested by the western pine beetle.

A recent breakthrough on the mass rearing of the southern pine beetle in bolt material and on artificial diets has been accomplished by Clark (10, 11) and Clark and Osgood (12, 13). Results of this research have made it possible to maintain populations of the insect for laboratory studies during periods when infestations are difficult to locate in the field.

A survey of site conditions by Lorio[3/] in east Texas, showed that Rains and Caddo soil series were frequently associated with southern pine beetle infestations. Virtually all infestation spots studied were on imperfectly or poorly-drained soils. Also, most stands were 40-to 50-

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3/ Lorio, P. L. 1963. Final progress report: survey of soil conditions and the occurrence of the southern pine beetle in Hardin County, Texas. SO-2203-6.1.

years-old and were well to densely stocked. Sites were good to excellent, but radial growth had slowed noticeably, especially in the high-density stands.

Research on the seasonal behavior and attack pattern of the beetle has been completed by Thatcher and Pickard in east Texas (38), and work is being continued in central Louisiana. In each of 3 years of study in Texas, the number and size of new infestations increased most rapidly during April, May, and June, but populations declined rapidly in the summer and fall. During the winter months, brood concentrations were greatest, and infestations extended up the stems. In midsummer, however, beetles occupied only the lower one third of the boles, probably because of competition with other bark-inhabiting species. Implications are that control measures should be intensified in the fall, winter, and early spring.

Research also is developing cheaper and safer spray formulations for suppressing the beetle. Bennett and Pickard (7) found that a BHC-water-base spray plus a wetting agent is as effective as the standard BHC-diesel oil solution for summer control. A pilot study to test emulsions of BHC and Lindane is being planned by the Insect and Disease Control Division, Region 8. The field work will be done by national forest crews in each of the Division's three Zones and will be repeated quarterly over a one-year period.

Current Research

The Forest Service is now concentrating its southern pine beetle research at Alexandria. Here, one soil scientist, one tree physiologist, and three entomologists are studying the seasonal behavior, physiology, and ecology of the beetle and investigating site, soil moisture, stand composition, and other environmental influences in relation to host physiological changes that affect the insect and its associated organisms. The general

aims of this team approach are to determine the causes of epidemics and to develop means of managing timber so that stands will be less subject to infestation.

The Project recently has started several fundamental studies, most of which are based on situations that are believed to predispose trees or stands to beetle attack. For example, beetle hazard areas in the southern flatwoods are repeatedly subjected to flooding and drought. These conditions vary seasonally or for more prolonged periods and may, by reducing tree vigor, make stands susceptible to beetle epidemics. A study in the West Bay Game Management Area of Louisiana is determining the seasonal and yearly changes that take place in soil moisture, and how these changes are related to root development and the occurrence of pathogenic root fungi and other soil microorganisms. The relationship of widespread loblolly decline, as affected by root fungi, to a continuing beetle outbreak is indicated.

Research on physiological changes in tree tissue in response to soil-moisture regime also is underway in the West Bay Area. This study on the effects of controlled drought and flooding upon changes in tree water balance and inner-bark constituents may explain how these changes affect the beetle's food requirements and the development of associated organisms such as fungi, yeasts, parasites, and predators.

Lightning-struck trees are very vulnerable to attack by the southern pine beetle, and brood production is typically greater than in other trees. Current research on the physiological factors in lightning-struck trees in relation to beetle attack and development is expected to provide clues as to why some non-lightning-struck trees are more likely to be attacked than others.

Smith (33, 34) has found that resin vapors from certain pine species are toxic to the western pine beetle. Similar research with the southern pine beetle is investigating the toxic effects of resins in the southern pines. The study may also show that environmental conditions such as drought, flooding, and lightning strike, cause quantitative changes in resin constituents and that these changes subsequently affect vapor toxicity and beetle survival. The quantity of resin flow and its duration, however, may be more important than vapor toxicity and this possibility may warrant investigation.

Fungal tubes, known as mycangia, recently have been found in the female southern pine beetle by Francke-Grossmann (18). These tubes open at the base of the front legs and contain one or two species of fungi that are probably associated with beetle nutrition. The histology and origin of the mycangia and the isolation, determination, and significance of the fungi are in progress at Alexandria. A fluid within the mycangia is believed to be produced by associated gland cells, and may be specific for maintenance of fungi within the tubes or in beetle galleries. The nutritional aspects of this research may have a bearing on beetle development in relation to physiological changes in inner-bark tissue. Also, the research may further refine artificial rearing techniques and ultimately provide an indirect method for controlling the beetle by depriving broods of essential nutrients. Antibiotic possibilities of the fluid may be of interest to the pathological and medical professions.

Another major research effort at Alexandria is the identification, habits, and importance of insect and mite enemies of the southern pine beetle. Preliminary work has been done with a clerid predator[4/], but present emphasis

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4/ Thatcher, R. C. and Pickard, L. S. 1966. Clerid beetle, Thanasimus dubius, as a predator of the southern pine beetle. (Accepted for publication by the Journal of Economic Entomology).

is on predaceous mites associated with the beetle. Immediate goals are to classify the numerous mite species and to work out the biology and ecology of promising candidates that may be cultured and released when host populations are at a low level. Closely related exotic mites from the western United States and Central America also are being investigated with a view toward introducing species that are compatible with indigenous ones. So far, 100 species of mites, many of them new to science, have been found associated with pine bark beetles. At least 8 species are predaceous and may prove useful as biological control agents.

Now in its third year, research at the Southern Institute of Forest Genetics is attempting to develop pines that are genetically resistant to the southern pine beetle. With the cooperation of the Texas Forest Service, scions from apparently resistant trees in a Texas epidemic area have been grafted and established at College Station, Texas. Additional grafts have been made from select trees in Louisiana and southwest Mississippi and are under study at the Institute. Scions from select trees in Honduras died in transit, but additional collections are planned.

Bioassays of gum components from select trees and checks are also being made and compared by the Institute. Results to date indicate that there are no qualitative differences in components from select and check trees, but there are quantitative differences. The relative attractiveness of these components to the beetle will be tested with an olfactometer.

Although most Forest Service research on the southern pine beetle is being carried out at Alexandria, some work is continuing at the Southeastern Station's Forestry Sciences Laboratory, Durham, North Carolina. This research involves basic studies on insect nutrition, sensory perception,

bark chemistry, and temperature extremes in relation to host attraction and beetle attack, development, and survival.

Forest Service research in the West that may be pertinent to the southern pine beetle problem involves studies of bark-beetle attractants, chemical control, population dynamics, sampling techniques, nutrition, and the relation of the chemistry and mechanism of tree resistance to beetle attack. Of particular interest is research on the isolation and synthesis of bark beetle attractants at the University of California and the Stanford Research Institute. Techniques developed by this project, supported by a Forest Service grant, will likely have application to the synthesis of the southern pine beetle attractant; and ultimately to the manipulation of field populations and control by spraying select trees with an attractant-insecticide combination. Researchers at the Pacific Southwest Forest Experiment Station's Insecticide Screening Project, plan to cooperate in developing such a formulation for western bark beetles.

Bark beetle research by southern universities is generously supported by industry and the U.S. Forest Service. Industry provides grants through the Southern Forest Disease and Insect Research Council sponsored by the Southern Pulpwood Conservation Association. One such grant currently supports research at Clemson University on the biological impact of checkered beetles (Cleridae) upon populations of pine bark beetles. Another, which is applicable to southern pine beetle research, provides for a study at Virginia Polytechnic Institute on the effect of insect parasites upon Ips beetle populations.

The Forest Service provides 5 grants to 3 southern universities for research directly related to the southern pine beetle. This research includes studies of factors that influence the attraction, movement, and

concentration of southern pine beetles in host trees, Duke University; the taxonomy of gamasid mites associated with southern pine beetles, North Carolina State College; and 3 studies at Northwestern State College of Louisiana titled "Qualitative and quantitative alterations in the nitrogen content of lightning-struck trees"; "Identification of the microflora in lightning-struck trees that may favor the southern pine beetle", and "Relation of Pygmephorus mites to the southern pine beetle."

Other research by educational institutions and state agencies includes: the correlation of climate (or weather) with bark beetle outbreaks in the Southeast, with particular reference to the southern pine beetle, Clemson University; the biology and effectiveness of clerid and ostomid predatory beetles as biological control agents of bark beetles, Duke University; the ecology of the southern pine beetle, University of Georgia; biology and control of bark beetles attacking conifers with special emphasis on sex attractants, sexual behavior, and reproduction in the southern pine beetle, University of Georgia; population studies of bark beetles in pine stands injured by Hurricane Betsy, Louisiana State University; biochemical variations in Dendroctonus frontalis, North Carolina State University; development of diets and rearing methods for studying the effects of certain environmental factors on the biology of the southern pine beetle, Texas A&M University; pilot studies on the evaluation of the currently recommended control method for the southern pine beetle, Texas A&M University and the Texas Forest Service; and the effects of avian predators on overwintering broods of the southern pine beetle, State of Virginia.

Continuing southern pine beetle investigations by the Southern Forest Research Institute (B.T.I. supported by Texas industry) are in

the area of field response to attractants; host selection behavior; collection and bioassay of attractants; and changes in the susceptibility of southern pines to beetle attack.

Research Attack Proposed

Long-range objectives of the Alexandria Project are to devise practical silvicultural, biological, and possibly other indirect control measures for the southern pine beetle under several diverse site conditions where epidemics are known to recur. These so-called beetle-hazard areas are in the flatwoods of the lower Coastal Plain, the loessial hills and terraces east of the Mississippi River, and the Appalachian Mountains, plateaus, and foothills.

The lack of information about the beetle, however, sharply handicaps applied research on indirect control methods. Priority studies, therefore, must fall in the broad category of basic research, primarily in insect biology and physiology, ecology, soil science, and tree physiology. Research in these fields will be aimed at securing fundamental knowledge of the immediate environmental factors affecting the southern pine beetle, its interrelationships with other insect species and microorganisms, situations that render trees susceptible to infestation, and the reasons for epidemic and endemic conditions.

Although not within the immediate scope of Project objectives, the urgent need for a concerted research effort in bark beetle toxicology must be emphasized. There is a pressing demand for developing more effective direct-control measures as a stop-gap until indirect-control goals are achieved. Furthermore, the application of insecticides may always be a necessity, particularly in emergency situations following hurricanes and other unpredictable disasters in extensive forest areas. Improved direct

suppression methods should be aimed at the screening of insecticides to secure safer, more economical, and selective control with minimum damage to beneficial forms; refining formulations, equipment and control techniques; isolating and synthesizing the southern pine beetle attractant; and developing the use of attractants to curtail widespread pesticide application.

In considering the needs for better direct controls and other proposed research, we recognize that no single organization is likely to have the resources to cope with the job in its entirety. Much that is contemplated here can and should be accomplished by the coordinated efforts of federal, state, and private research agencies, educational institutions, specialized laboratories, and other groups that are qualified to undertake segments of the problem to meet major goals.

The following proposals for specific priority studies are restricted to foreseeable limitations of Project staffing at Alexandria. They are in direct line with present aspirations to develop silvicultural and biological methods for preventing or minimizing bark beetle outbreaks.

Specific Studies Indicated and Their Priorities

The numbered subjects listed below will have equal status in the Project's research program. Specific studies related to them are in order of priority.

1. Insect biology and physiology: Basic to progress in applied research is a thorough knowledge of insect behavior and life processes. Detailed research is needed as follows:

Population studies of the southern pine beetle: --seasonal behavior, pattern of attack, and development (SO-2203-1.1).

The effect of pine resin vapors on the southern pine beetle (SO-2203-1.10).

Characteristics of mycangia and associated microorganisms in the southern pine beetle (SO-2203-1.13).

The significance of mycangial fungi in relation to beetle nutrition and brood survival.

Variations in life history, seasonal behavior, and pattern of attack of the southern pine beetle that are associated with climatic and locality differences.

Relationships between and within the 5 bark-beetle species and their associated inner-bark forms during epidemic and endemic periods.

Genetic variations of the southern pine beetle that may affect population fluctuations.

Genetic variations of the southern pine beetle within the insect's range.

2. Site and host-physiological relationships: Reference is made to problem analyses by Lorio[5/] and Hodges[6/] pertaining to site and tree-physiological conditions and southern pine beetle attack. Research on the processes that render trees or stands subject to initial, continuing, and repeated infestation, and that favor or oppose successful brood development should include or be supported by the following studies:

Soil moisture regime under loblolly pine in a southern pine beetle problem area (SO-2203-6.3).

Physiological changes in plant tissue in response to soil-moisture regime (SO-2203-6.5).

5/ P. L. Lorio. 1963. A problem analysis: site conditions and southern pine beetle attacks. SO-2203-6.0.

6/ J. D. Hodges. 1966. A problem analysis: tree physiology in relation to southern pine bark beetles. SO-2203-7.0.

Physiological factors in lightning-struck trees in relation to bark-beetle attack and development (SO-2203-1.11).

Qualitative and quantitative alterations in the nitrogen content of lightning-struck trees (SO-2203-7.1; cooperative study with Northwestern State College of Louisiana).

Identification of microflora in lightning-struck trees that may favor the southern pine beetle (W.O.; cooperative study with Northwestern State College of Louisiana).

Soil, soil fungi, and root conditions associated with loblolly pine decline and southern pine beetle outbreaks.

Production of carbonyl compounds by blue-stain fungi in association with the southern pine beetle.

Tree physiological reasons for seasonal differences in beetle-attack patterns, population fluctuations, and brood concentrations.

Time effects of drought and flooding on recovery of pines to full vigor.

Relation of maximum and minimum ambient temperatures to subcortical temperatures and inner-bark moisture associated with beetle-brood survival.

A comparison of site, environmental conditions, and the morphology and physiology of host trees in beetle-hazard areas and areas where outbreaks do not occur.

Site, tree morphology, and tree physiology in relation to beetle attack.

3. Associated forms affecting the beetle: An evaluation of the control effectiveness of parasites, predators, entomophagous fungi, and other associates should include the following studies:

Mites associated with the southern pine bark beetles - identification and biology (SO-2203-1.7).

The relationship of Pygmephorus sp.(Acarina:Pyemotidae) to the southern pine beetle (SO-2203-1.9; cooperative study with Northwestern State College of Louisiana).

Techniques for mass rearing of predaceous and parasitic mites.

Identification of insect parasites and predators and other associated organisms capable of materially affecting beetle populations.

Biology, ecology, and mass culture of promising insect parasites and predators.

Isolation and identification of entomophagous fungi and viruses and their pathogenicity to different life stages of the beetle.

Conditions necessary for optimum development and effectiveness of entomophagous fungi and viruses.

The identification, biology, ecology, and culture of important nematode parasites of the southern pine beetle.

Morphological and physiological features of host trees that influence associated organisms as control agents for the southern pine beetle.

Variations in numbers and relative importance of organisms associated with southern pine beetle population trends.

Development of improved biological evaluation and economic appraisal techniques which will aid in determining the need for initiating, continuing, or terminating direct control measures.

The proposals outlined above, stress the importance of basic knowledge from which practical controls can be developed. They do not attempt to go beyond immediate needs and foreseeable goals. Modern skills, techniques, and equipment are constantly opening new possibilities and new areas in heretofore unexplored fields. The course of applied

research and the definition of studies necessary to meet final objectives, therefore, will be left for future revisions of the analysis. The general areas of this research will encompass:

Silvicultural means for reducing losses from the southern pine beetle with major considerations to site and stand conditions; and to developing a beetle-risk-class system for southern pine forests.

Biological means for suppressing the southern pine beetle by the mass rearing and timely release of natural enemies; and manipulating the forest environment to encourage optimum population levels of these beneficial forms.

Time Schedule For Studies To Be Started

Studies already started are indicated by the study-plan number. Expansion of the research is contingent upon staff expansion, particularly by the addition of aids and technicians.

Current Pertinent Literature*

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*Earlier literature has been reviewed by Dixon and Osgood (15), Osgood (29), and Thatcher (36, 37).

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ADDENDUM

Thatcher's "Project Analysis: The Southern Pine Bark Beetles" is superseded by this report; by the 2.0 "Problem Analysis: The Black Turpentine Beetle," dated August 1962, and Supplement dated July 1966; and by the 3.0 "Problem Analysis: Southern Ips Engraver Beetles," now in preparation.